Evaluation of Single and Multi-Beam Sonar Technology for Water Column Target Detection in an Acoustically Noisy Environment

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EVALUATION OF SINGLE AND MULTI-BEAM SONAR TECHNOLOGY FOR WATER COLUMN TARGET DETECTION IN AN ACOUSTICALLY NOISY ENVIRONMENT

by

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ABSTRACT

Melvin, Gary D., Cochrane, Norman A., and Fitzgerald, Pat. 2009. Evaluation of Single and Multi-beam Sonar Technology for Water Column Target Detection in an Acoustically Noisy Environment. Can. Tech Rep. Fish. Aquat. Sci. 2840: vii + 27p.

Acoustic backscatter measurements in the Bay of Fundy served to evaluate the use of echo-sounders and sonars for monitoring fish behaviour in tidal currents near Tidal In-Stream Energy Conversion (TISEC) devices. Acoustic monitoring throughout the water column appeared feasible at one site in Western Passage off southwest New Brunswick, but not so at the adjacent, more turbulent, "Old Sow" location. Monitoring in Minas Passage near Black Rock off Parrsboro, NS, was ineffective within the upper half of – and occasionally throughout – the water column due to entrainment and vertical advection of bubbles, causing intense non-biological backscatter. Bubbles appeared entrained by tide rips near Black Rock and drifted downstream several kilometers in a narrow wake. No anomalous absorption was detected at 120 kHz. Our observations question the effective use of acoustics at highly turbulent sites.

RÉSUMÉ

Melvin, Gary D., Norman A. Cochrane, et Pat Fitzgerald. « Evaluation of Single and Multi-beam Sonar Technology for Water Column Target Detection in an Acoustically Noisy Environment », *Rapp. tech. can. sci. halieut. aquat.*, 2840: vii + 27p., 2009

On a utilisé la rétrodiffusion acoustique dans la baie de Fundy afin d'évaluer l'efficacité des échosondeurs et des sonars pour surveiller le comportement des poissons dans les courants de marée à proximité des dispositifs TISEC (Tidal In-Stream Energy Conversion). La surveillance acoustique dans toute la colonne d'eau a semblé possible à un endroit du chenal Western Passage, au large de la côte sud-ouest du Nouveau-Brunswick, mais pas au site situé à proximité des rapides « The Old Sow » où l'eau est plus turbulente. La surveillance acoustique dans le passage Minas, près de Black Rock, au large de Parrsboro, en Nouvelle-Écosse, s'est révélée inefficace dans presque toute la colonne d'eau, mais surtout dans la partie supérieure de la colonne, à cause de l'entraînement et de l'advection verticale des bulles, ce qui provoque une très forte rétrodiffusion non biologique. Les bulles semblaient être entraînées par des remous de marée près de Black Rock, puis elles ont dérivé au fil du courant sur plusieurs kilomètres, produisant un sillage étroit. On n'a décelé aucune absorption anormale à 120 kHz. Nos observations remettent en question l'efficacité de l'acoustique dans des eaux très turbulentes.

INTRODUCTION

GENERAL

Recent interest in the development of tidal power facilities at several locations in the Bay of Fundy has prompted serious concerns about the impact these developments will have on fish and habitat. A pilot project to explore the feasibility of Tidal In-Stream Energy Conversion (TISEC) devices in the Bay of Fundy will see the installation of one or more turbines in the fall of 2009 at sites in Minas Passage, NS. Unlike traditional tidal generation systems that utilize a barrage to store energy, these systems will be fixed to the substrate in high flow areas and directly extract energy from the bi-directional natural flow. From a biological perspective there is much uncertainty about how fish will react to the presence of the turbines; whether their behaviour will be to avoid the structures or whether there will be an increased risk of injury/mortality due to direct interaction/contact with the devices.

All proposed locations for tidal power development have resident and migratory fishes and invertebrates present throughout most of the year. In the upper Bay of Fundy a number of anadromous fish species transit the Minas Passage annually on their way to spawn in the rivers flowing into Minas Basin (e.g. salmon, striped bass, gaspereau, shad, and smelt). The adults and juveniles of these same species also migrate through the proposed development sites on their outward journey to the sea. Some are believed to linger in the upper Bay of Fundy for several months before moving on, thereby increasing their risk of interaction with tidal power devices. Permanent and seasonal resident fishes are likely subjected to even greater risks in that many repetitively move in and out of the Basin with the tides, thus potentially exposing them to multiple interactions daily. Such species include summer-feeding migratory American shad, and spring and summer spawning Atlantic herring aggregations.

Other proposed development locations, such as those along the New Brunswick Fundy coast are characterized by adult and juvenile anadromous species migrating through the sites, but not to the same extent as Minas Passage. The real concerns in these areas are the resident species. In Western and Head Harbour Passage, adult and juvenile herring are abundant throughout the year and could be subjected to an increased risk of mortality on a daily bases. The region is a major herring nursery area for local, regional, and international fish stocks. Large aggregations of herring are known to occur throughout the area and to move with the tide. Other species such as mackerel, cod, and flatfish are also common at most proposed development sites.

Large tidal variations and currents are a prerequisite for TISEC development. Unfortunately, these same conditions make it difficult to assess and monitor marine life in the vicinity of the development sites by rendering use of conventional sampling gear and methods ineffective in evaluating potential environmental impacts and risks.

Multi-beam sonar technology such as the Simrad MS2000 has the potential for wide-swath angle acoustic target detection under a variety of situations. Combined with more conventional multi-frequency, single or split-beam fisheries echo-sounders this technology could provide a mechanism to count and monitor the occurrence, distribution, and potentially behaviour of fish near or around physical structures such as submerged TISEC devices. However, both single/split-beam and multi-beam fish detection technologies can be compromised by interfering backscatter from non-biological targets, such as air bubbles, or their quantitative capacities degraded by anomalous acoustic absorption in strongly aerated water. The waters around the proposed tidal power development sites are extremely dynamic; they sometimes contain high sediment loads, and are potentially saturated with air during certain portions of the tidal cycle. Acoustic systems seem highly advantageous for monitoring fish targets approaching and perhaps even moving downstream from the turbines. Nevertheless, it is uncertain how such a system would perform under extremely turbulent and fast-flowing tidal conditions.

The primary goal of this project is simply a "proof of concept" That is, to determine if acoustic technology can be used to monitor the distribution and abundance of targets (i.e., fishes) in the water column around the proposed turbines and, if so, to note any limitations relative to tidal flows and turbulence as to when, where, and how the technology might be used.

STUDY AREA

Two general development locales were selected to investigate the effects of strong currents and turbid water conditions on the acoustic gear and signal returns. The first locale (Figure 1), situated in Western Passage, represents a narrow channel between Deer Island, New Brunswick and Eastport, Maine with relatively low suspended sediments. Tidal amplitudes in the area average about 6 m, with spring tides reaching greater than 7 m, and peak tidal currents reaching 3 - 5 knots (1.5 - 2.6 m/s). Water depths are approximately 75 – 125 m. The area of study in Western passage included two proposed development sites and the nearby "Old Sow" area known for its turbulent conditions during high flow periods of the tidal cycle (Figure 2). The second locale was in the northern portion of Minas Passage (Figure 1), with the proposed initial development site located just west of Black Rock in an area known for strong tidal currents, turbid waters, and coarse and mobile bottom sediments interspersed with regions of exposed bedrock (Figure 3). Tidal currents range from 6 - 8 knots (3.0 - 4.1m/s) during maximum flow with an average tidal amplitude of 10 m and peaks of greater than 13.0 m (Figure 4 - Tides & Currents Version 1.05). Water depths in the vicinity of the development site are 30 – 70 m depending upon the tide.

METHODS

INSTRUMENTATION

Two acoustic systems were deployed to investigate the effects of turbulent waters at the proposed sites for TISEC development: (i) a split-beam 120 kHz echo-sounder (Simrad

EK60) and (ii) a multi-beam sonar (Kongsberg Mesotech MS2000). The MS2000 sonar technology provides quantitative sample data throughout the water column from 128 simultaneously synthesized beams over a swath of 180°. Maximum ping rate varies with range setting, but for ranges <100 m, rates in the order of 2-3/sec are easily attainable. The data are stored digitally with playback and analytical capabilities. Both the EK60 split-beam transducer (120 kHz, 7° beam angle) and the MS2000 sonar head (200 kHz, 180° swath, beam angle 2.5° x 20°) were pole-mounted and deployed over-the-rail from a small vessel (Figure 5). The R/V *OSPREY* was used in Western Passage and the F/V *TIDE FORCE* in Minas Passage. A Standard Horizon CP 300i GPS unit provided NEMA 083 serial data streams for time and position to both acoustic systems. The data were logged using system-specific software; Simrad ER60 for the EK60 echo-sounder and Simrad MS2000 Version 1.4.2 for the multi-beam sonar. EK60 data were analyzed with Echoview Version 4.6 and the MS2000 data with MS2000 Version 1.4.2 software. The EK60 was calibrated November 5, 2008 with a 38.1mm tungsten carbide sphere using standard methods.

SURVEY

The two acoustic systems operated simultaneously and continuously along the survey tracks shown in Figures 2 & 3. The survey approach varied slightly between the two locations. In Western Passage the goal was to collect acoustic data at 2 of 3 proposed sites and the nearby "Old Sow" area during variable phases of the tidal cycle. Acoustic monitoring occurred during a high-to-low tide ebb cycle. In Minas Passage the focus was on the proposed development site just west of Black Rock. Data collection again occurred during a high-to-low ebb tide cycle. Unfortunately, about 3 hours into the data collection a mounting bracket broke and sampling had to be suspended for the day.

RESULTS

Standard outputs from the (single) split-beam EK60 and multi-beam MS2000 systems are shown in Figures 6 and 7 respectively. For the EK60, the echogram represents approximately 10 minutes of recording at a ping rate of 1 per second, while the multi-beam sonar output represents a single ping covering a swath of 180° perpendicular to the vessel fore-aft line. Displaying multiple pings from the MS2000 would require 3D presentation which has not been attempted. The effective range of the multi-beam swath is limited to the instantaneous water depth directly beneath the transducer due to bottom echo saturation. Only very strong signal returns such as from the lateral bottom profile can be detected outside the effective range.

Acoustic data were collected in Western Passage from 11:51 to 18:00 on November 27, 2008 encompassing almost the entire ebb tide cycle. Water conditions during the survey period are illustrated in 4 photos (Figure 8). The overall distribution of backscatter along the vessel track is presented in Figure 9. Three echograms were selected to characterize the acoustic observations at the proposed development sites (Figure 10). Corresponding single pings from the MS2000 have been selected for comparison (Figure 11). In Figure 10, the upper panel (A) illustrates the strong signal return from accumulated rockweed

and other apparently downward-advected, but unidentified, near-surface scatterers. Below the surface scatter is a small school of fish at about 25-30 m depth. Both the surface scatter and the school of fish are visible in the multi-beam sonar section that slices through the school (Figure 11A). The middle panel (Figure 10B) shows an apparent frontal convergence zone and the backscatter associated with the extended downward-sloping discontinuity in water properties. Individual targets are visible below the zone and two small aggregations of fish (likely herring) are also clearly defined just above the inclined frontal surface. The long streaks observed in both the upper and middle panels are characteristic of multiple hits on a single target due to a near stationary position at the time of recording. Again in Figure 11B the multi-beam sonar clearly shows the small school of fish directly under the vessel. However, it is important to note that several small aggregations of fish occur around the same depth on either side of the vessel which are undetectable by the single beam system. Single targets observed in Figure 10C are typical of a vessel in motion with 1 or perhaps 2 hits on a single target. Consistent results are again obtained with the multi-beam sonar (Figure 11C). In general, at the two Western Passage sites it was possible to distinguish fish-like targets and small aggregations of fish throughout most of the water column.

At the Old Sow, water turbulence was much greater than at the designated development sites in Western Passage. Numerous small to medium size whirlpools, up-wellings, and shear zones are readily visible in the water surface topography (Figure 8). During peak flow periods acoustic detection of individual targets and aggregations of fish in this area becomes uncertain. Figure 12A shows the strong backscatter seemingly associated with the turbulence that, in some cases, extends nearly to bottom. However, between extended patches of intense backscatter individual fish and small schools can be detected. The multi-beam image (Figure 13A) shows the intense backscatter extending more than 50m to both sides of the vessel and to depths of 25m or more. At near low tide (minimal tidal currents) backscatter associated with turbulence is still present, but greatly reduced in intensity and limited to the upper 20m of the water column (Figure 12B). Discrete targets below the turbulence are clearly visible. The multi-beam profile (Figure 13B) shows weak scattering in the near-surface waters and a few individual scatterers through the water column consistent with the split-beam echogram shortly after 19:10.

The survey in Minas Passage was undertaken on 10 Jan. 2009 aboard a local vessel equipped to pole-mount the acoustic equipment. The vessel left Halls Harbour near high water and proceeded across Minas Passage to near Black Rock on the Parrsboro shore. Again both the Simrad MS2000 and EK60 were deployed with the transducers about 2 m below the surface. The vessel proceeded westward from Black Rock for several kilom ,es and encompassed the proposed site for TISEC device evaluation. The bottom, at an average depth of about 50 m, appeared visibly rough and irregular on the echograms and from prior geological surveys (Parrott et al. 2008; Hagerman et al. 2006) was known to consist of exposed bedrock with adjacent areas of coarse gravel. Several survey transects approximately parallel to the coast (in the direction of the local tidal current) were conducted. The water column backscatter along the vessel track was strongest directly downstream from Black Rock on the out-flowing tide (Figure 14). North and south of this track the backscatter was less pronounced. It is, however, conjectured that

this difference is directly related to intense tide rips generated by the flow around and extending westward from Black Rock (Figure 15).

Echograms from the EK60, representing two general areas immediately west of Black Rock, illustrate the difference in signal returns just outside and inside the tide rip zone (Figure 16). The upper panel echogram was collected slightly north of the westerly rip and clearly shows some intermittent backscatter near the surface as the vessel approaches the vicinity of Black Rock. It is possible to discern relatively weak individual scatters from the surface to the bottom. However, in the tidal rip (Figure 16, lower panel), it is virtually impossible to distinguish anything but the intense diffuse backscatter which extends from the surface to the bottom. MS2000 sections for several selected points on the EK60 echograms show what is happening perpendicular to the survey trajectory. Section locations along the track can be identified by matching times after accounting for an additive 3 minute 20 second time-base offset from sounder to sonar. Outside the rip it is possible to observe multiple targets in the water column on either side of the vessel (Figure 17, upper panel). In the middle panel these are large regions of intense, diffuse backscatter extending 45 m or more on the starboard side, while 7 seconds later it extends for 45m or more on both sides of the vessel and from surface to bottom (bottom panel). In these conditions acoustic targets such as fish or schools of fish are indiscernible from the surrounding scattering at any depth.

DISCUSSION

Entrained air bubbles are strong water column acoustic scatterers and, in high concentrations, strong acoustic absorbers. Breaking waves play an important role in the amount of air entrapped in near-surface waters. Under calm conditions wave action is minimal and the zone of air bubbles near the surface narrow to virtually non-existent. However, with breaking waves this zone intensifies and deepens. In areas subject to strong winds or currents, deep vertical circulations can be excited. In such cases the aerated layer can be advected downward resulting in strong, non-biological backscatter extending through an appreciable fraction of the water column. This aerated water could potentially obscure normal sonar and echo-sounder observations of fish and in extreme cases even attenuate echoes from distant biological targets. Wind directions and strengths at several stations around the Bay of Fundy on November 27, 2008 and January 10, 2009 are presented in Figures 18 and 19 respectively, this data having been obtained from the Environment Canada, National Climate Data and Information Archive.[1] Wind conditions during the two, one-day studies contrasted sharply. In Western Passage the winds were virtually non-existent (<10 km/hr) while in Minas Passage strong, WNW winds increasing to 30-40 km/hr (estimated by the captain) by mid-afternoon were present. In the latter instance, surrounding land meteorological observations (Figure 19) indicated somewhat lower WNW winds of 10 – 20 km/hr perhaps due to the less exposed settings of the land stations.

In general, the water column in Western Passage was quite transparent acoustically with fish detection presenting few problems for surface-deployed or vessel-mounted

[1] Data available online through portal at http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html

equipment. At least one strong frontal convergence was noted visually characterized at its surface intercept by a narrow band of rough water and accumulated flotsam. Below-surface, the convergence zone was marked acoustically by a sloping interface traceable to some depth. A number of fish echoes were observed in its immediate vicinity including small schools of possibly juvenile herring. Throughout the survey, winds were calm with the water surface either "glass smooth" or only slightly ruffled. In spite of the absence of wind and surface waves, floating weed was observed to organize in parallel lines similar to those expected of Langmuir cells (these lines were distinct from the apparent frontal convergence). Acoustic scattering appeared enhanced within the lines of weed to depths of about 10 m although the weed itself was confined to the top meter or less (visual estimate). Vertical circulation cells, seemingly necessary to explain the weed alignment, could be of a similar nature to those observed in parts of the Gulf of Maine by Pershing et al. (2001) and attributed to the interaction of strong tidal currents with bottom irregularities.

In the "Old Sow" area off the southern tip of Deer Island, marked by the confluence of two tidal streams in the presence of precipitous bottom bathymetry, intense backscatter was observed through most of the water column. The area is known for its strong currents, turbulent waters, and whirlpool vortices during certain periods of the tidal cycle. The intense backscatter would seem most likely generated by temperature/salinity microstructure (Sandstrom et al. 1989; Seim et al. 1995; Wiebe et al. 1997) since wind conditions were virtually calm and no surface air entrainment from breaking waves or tide rips was evident. Microstructure generation might be expected from the intense vertical and horizontal mixing of contrasting and otherwise density-stratified water masses in a confluent estuarine environment. Nevertheless, in the absence of high resolution temperature/salinity profiles this generation mechanism must remain conjectural. It is possible that turbulent features and small confluent eddies observed on the water surface entrapped air and also contributed to the total backscatter. Some intense fish schools – almost certainly herring - were encountered. However, in several instances it was uncertain whether fish schools or backscatter of non-biological origin was being observed. A number of seals were present in the area and these could also be producing occasional strong acoustic echoes at depth.

In Minas Passage it was noted that ebb tide rips extended west from Black Rock. It is postulated that these rips efficiently entrained air at the surface, subsequently vertically mixed and systematically advected down to 25 – 30 m depths, resulting in sufficient diffuse backscatter to make discernment of fish echoes difficult or impossible in the upper half (or more) of the water column. Observed by eye, tide rips produce highly confused seas. Superimposed, short-wavelength wave trains result in steep-sided non-linear features which efficiently interact with the local wind field to generate white caps and near-surface bubbles. Several kilometres west of Black Rock the rips subsided but air bubble entrainment in the upper half of the water column was still apparent evidenced by semi-periodic vertical backscattering plumes extending in select cases from the surface nearly to bottom. The plumes may represent downward advection of upper water column bubbles in wind-driven Langmuir–like cells (Zedel & Farmer 1991) considering the lack of density stratification in the upper reaches of the Bay of Fundy – a well-mixed

water column would seemingly argue against a microstructure backscatter origin. Alternatively, the apparent vertical circulation cells may be excited by bottom tidal friction, or a combination of surface wind stress and bottom friction. Regardless of the circulation mechanism, an air-bubble origin for the intense plume scattering – as opposed to small fish or zooplankton - is strongly suggested by the high scattering levels and the diffuse appearance of the intensely scattering plumes. Nevertheless, the scattering plumes did not seem to noticeably attenuate bottom echoes (Appendix 1).

As noted previously, roughly parallel transects both north and south of the rips downstream of Black Rock encountered much lower levels of backscattering in the upper water column. Several strong fish echoes were seen on the MS2000 multi-beam. Few, if any, of these echoes appeared to pass directly under the EK60 transducer so as to permit split-beam detection and quantification of their acoustic target strength. By mid-afternoon, when data acquisition had to be curtailed, general wave action had increased and water column acoustic conditions had deteriorated sufficiently that the effects of tidal flow and rip-currents were less certain. Note that the WNW wind over Minas Passage during the survey would suggest a large fetch for wave energy to grow and waves to steepen and break in the face of an opposing current.

CONCLUSIONS

GENERAL

Strong tidal streams tended to be accompanied by intense acoustic backscatter frequently sufficient to obscure any acoustic backscatter arising from isolated or aggregated fish throughout a significant fraction of the water column. This backscatter may arise from surface-entrained air bubbles, generated by breaking surface waves associated with tide rips, that are subsequently downward advected 20 – 30 m or occasionally deeper. The downward advection arises from spatially periodic or semi-periodic vertical component circulations excited by surface wind/wave interactions, and/or bottom tidal friction over a rough substrate, and/or intense shear in the wake of obstacles, such as Black Rock. Another backscatter mechanism more characteristic of estuarine settings may be temperature/salinity microstructure generated by intense tidal turbulent mixing of an otherwise density stratified water column. However, the relative contributions of bubble and microstructure backscatter in any particular instance lies beyond the scope of the current work.

In the absence of wind disturbances, fish detection appears possible over the entire water column depth at the proposed tidal sites in Western Passage, even during the strongest portions of the tidal current cycle. However, no observations were conducted with significant wind and surface waves present. Fish detection in the adjacent "Old Sow" area would appear problematic throughout most of the water column during the stronger current portions of the tidal cycle even with calm wind and sea conditions. The "Old Sow" is not a currently designated turbine deployment site.

In Minas Passage acoustic fish detection would appear practical only in the lower half of the water column in the tide rip stream proceeding downstream from Black Rock, at least during portions of the tidal cycle. Lack of any detectable attenuation of acoustic bottom echoes transiting the near-surface backscattering plumes would indicate that effective echo-sounding of the lower water column may be feasible from a surface platform, provided the lower portions of the water column are not directly obscured during certain portions of the tidal cycle by *in situ* diffuse backscatter. Acoustic conditions in the upper half of the water column west of Black Rock could very possibly be more favourable on a flood tide or even in calmer wind conditions but this is unverified. Out of the tide rip and its persistent "fossil" stream of aerated water, acoustic conditions appear considerably more favourable for surface observations.

RECOMMENDATIONS

Acoustic technology can be used to detect and monitor the distribution and abundance of targets in the water column at several of the proposed tidal power development sites in the Bay of Fundy. However, there appear to be limitations on when and where the technology can be effectively used, especially at the more turbulent sites. Consideration must be given to the physical characteristics of the development site in the selection of the monitoring technology and its deployment method. Of the two general areas examined, the area just west of Black Rock during the ebb tide represented the worst case scenario. In the rips it was virtually impossible to detect fish from the background noise, especially in the upper ½ of the water column. In similar situations consideration might be given to deploying a bottom mounted (looking-up) transducer to guard against any anomalous acoustic attenuation from upper water column bubble clouds – although such attenuation was not detected in our present study utilizing the indirect technique of examining statistical variations in the bottom-reflected echo strength[1]. At all sites it is recommended that a system with a broad swath (e.g., MS2000 multi-beam sonar, Didson Imaging sonar) be utilized to detect and monitor fish.

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[1] The main argument for bottom-mounted acoustic equipment is to provide stability and accurate fixed positions of the acoustic transducers relative to any proximate tidal turbines over extended observation periods.

REFERENCES

Hagerman, G., Fader, G., Carlin, G., and Bedard, R. 2006. Nova Scotia Tidal In-Stream Energy Conversion (TISEC) Survey and Characterization of Potential Project Sites. EPRI North American Tidal Flow Power Feasibility Demonstration Project, Phase 1- Project Definition Study, Report EPRI-TP-003 NS Rev 2, [report online], 97 p. http://oceanenergy.epri.com/streamenergy.html (accessed 21 April 2009). Specify: "TP-003-NS Rev 1 Nova Scotia Site Survey Report".

Parrott, R. D., Todd, B. J., Shaw, J., Hughes Clarke, J. E., Griffin, J., McGowan, B., Lamplugh, M., and Webster, T. 2008. Integration of multibeam bathymetry and LiDAR surveys of the Bay of Fundy, Canada. Proceedings of the Canadian Hydrographic Conference, Paper 6-2, 15 p.

Pershing, A. J., Wiebe, P. H., Manning, J. P., and Copley, N. J. 2001. Evidence for vertical circulation cells in the well-mixed area of Georges Bank and their biological implications. Deep-Sea Research II 48: 283 – 310.

Sandstrom, H., Elliott, J. A., and Cochrane, N. A. 1989. Observing groups of solitary waves and turbulence with BATFISH and echo-sounder. J. Phys. Oceanogr. 19: 987 – 997.

Seim, H. E., Gregg, M. C., and Miyamoto, R. T. 1995. Acoustic backscatter from turbulent microstructure. J. Atmos. Ocean. Technol. 12: 367 – 380.

Wiebe, P. H., Stanton, T. K., Benfield, M. C., Mountain, D. G., and Greene, C. H. 1997. High-frequency acoustic volume backscattering in the Georges Bank coastal region and its interpretation using scattering models. IEEE J. Ocean. Eng. 22(3): 445 – 464.

Zedel, L. and Farmer, D. 1991. Organized structures in subsea bubble clouds: Langmuir circulation in the open ocean. J. Geophys. Res. C. Oceans. 96 No. C5: 8889 – 8900.

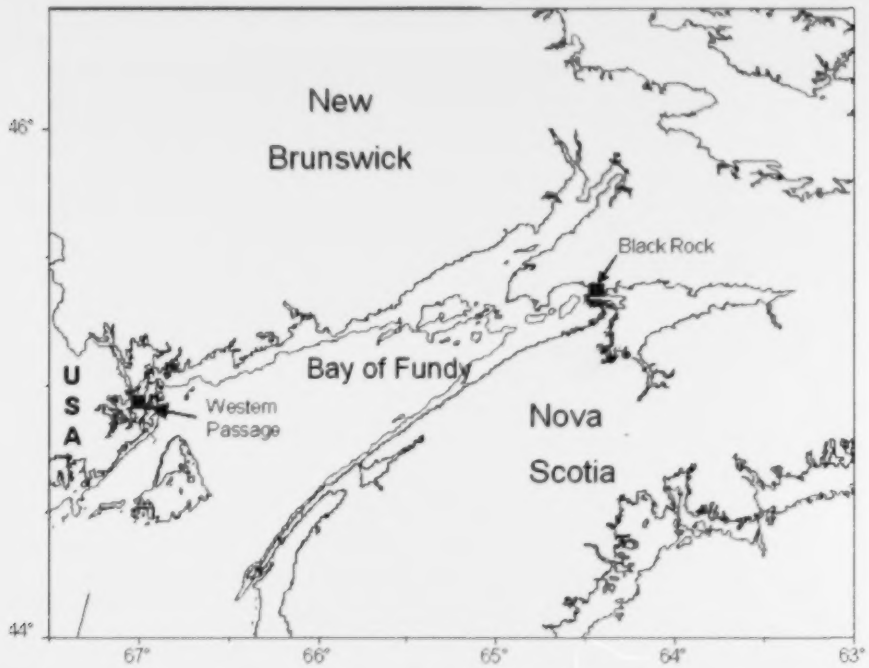

Figure 1. Map of the Bay of Fundy and the two test sites in Head Harbour Passage and the Minas Passage. Study sites (arrows) located near Eastport and Parrsboro respectively.

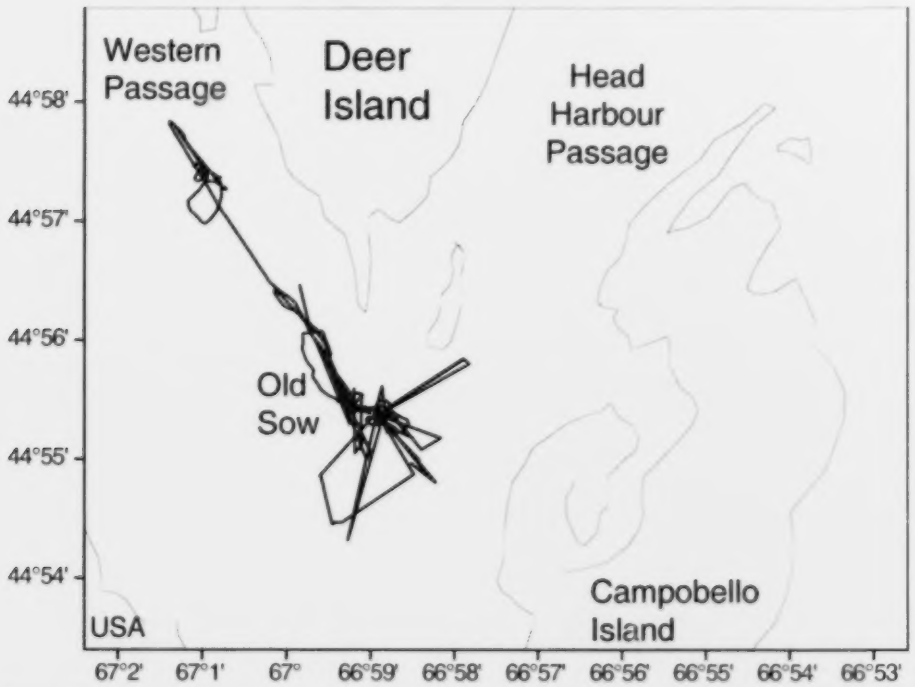

Figure 2. Survey location and vessel track of the *OSPREY* in Western Passage on November 27, 2008.

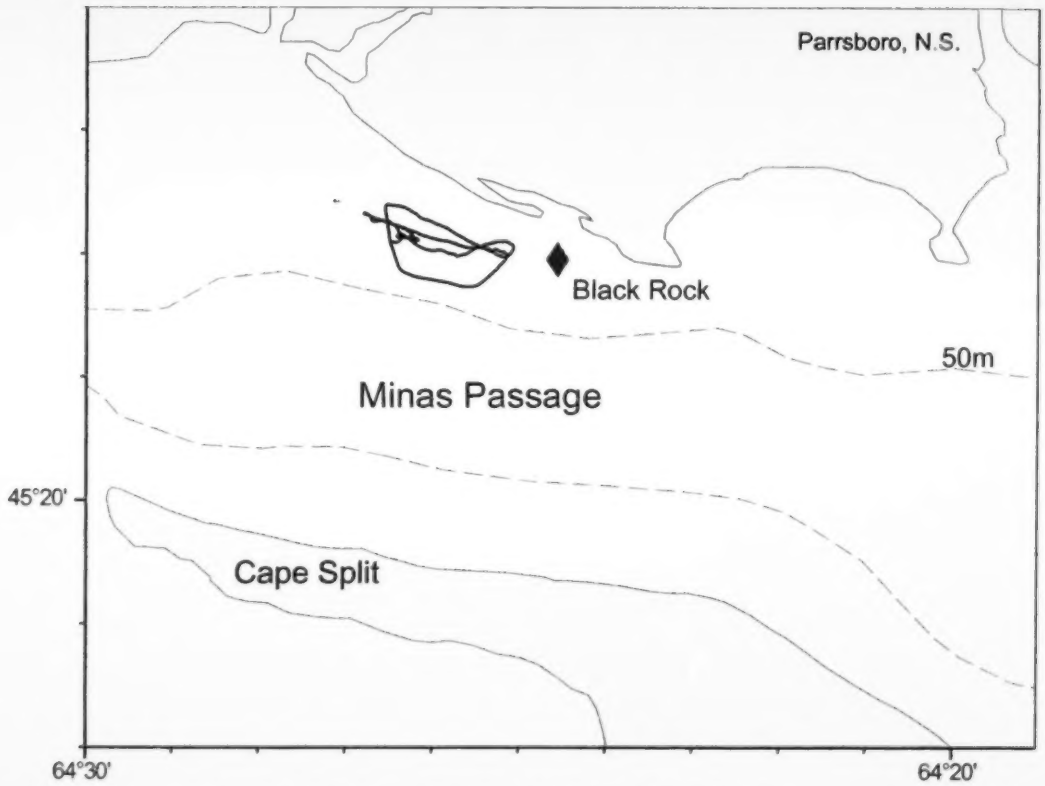

Figure 3. Survey location and vessel track of the *TIDE FORCE* just west of Black Rock in Minas Passage on January 10, 2009.

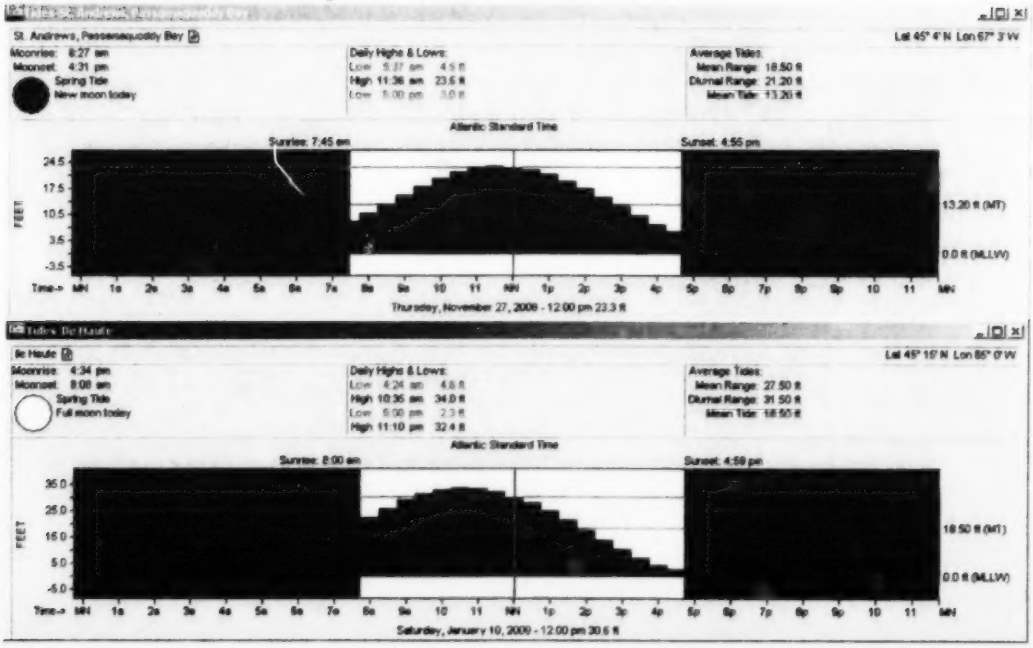
St. Andrews, Passamaquoddy Bay
Lat 45° 4' N Lon 67° 3' W
Moonrise: 8:27 am
Moonset: 4:31 pm
Spring Tide
New moon today
Daily Highs & Lows:
Low 5:27 am 4.5 ft
High 11:36 am 23.6 ft
Low 5:00 pm 3.0 ft
Average Tides:
Mean Range: 18.50 ft
Diurnal Range: 21.20 ft
Mean Tide: 13.20 ft
Atlantic Standard Time
Sunrise: 7:45 am
Sunset: 4:55 pm
FEET
24.5
17.5
10.5
3.5
-3.5
13.20 ft (MT)
0.0 ft (MLLW)
Time-> MN 1a 2a 3a 4a 5a 6a 7a 8a 9a 10 11 NN 1p 2p 3p 4p 5p 6p 7p 8p 9p 10 11 MN
Thursday, November 27, 2008 - 12:00 pm 23.3 ft
Ile Haute
Lat 45° 15' N Lon 65° 0' W
Moonrise: 4:34 pm
Moonset: 8:08 am
Spring Tide
Full moon today
Daily Highs & Lows:
Low 4:24 am 4.6 ft
High 10:35 am 34.0 ft
Low 5:00 pm 2.3 ft
High 11:10 pm 32.4 ft
Average Tides:
Mean Range: 27.50 ft
Diurnal Range: 31.50 ft
Mean Tide: 18.50 ft
Atlantic Standard Time
Sunrise: 8:00 am
Sunset: 4:59 pm
FEET
35.0
25.0
15.0
5.0
-5.0
18.50 ft (MT)
0.0 ft (MLLW)
Time-> MN 1a 2a 3a 4a 5a 6a 7a 8a 9a 10 11 NN 1p 2p 3p 4p 5p 6p 7p 8p 9p 10 11 MN
Saturday, January 10, 2009 - 12:00 pm 30.6 ft

Figure 4. Tidal information for St. Andrews, NB on November 27, 2008 and the Ile Haute on January 10, 2009, representing Western Passage and Minas Passage study sites, respectively (Source: Tides & Currents Version 1.05).

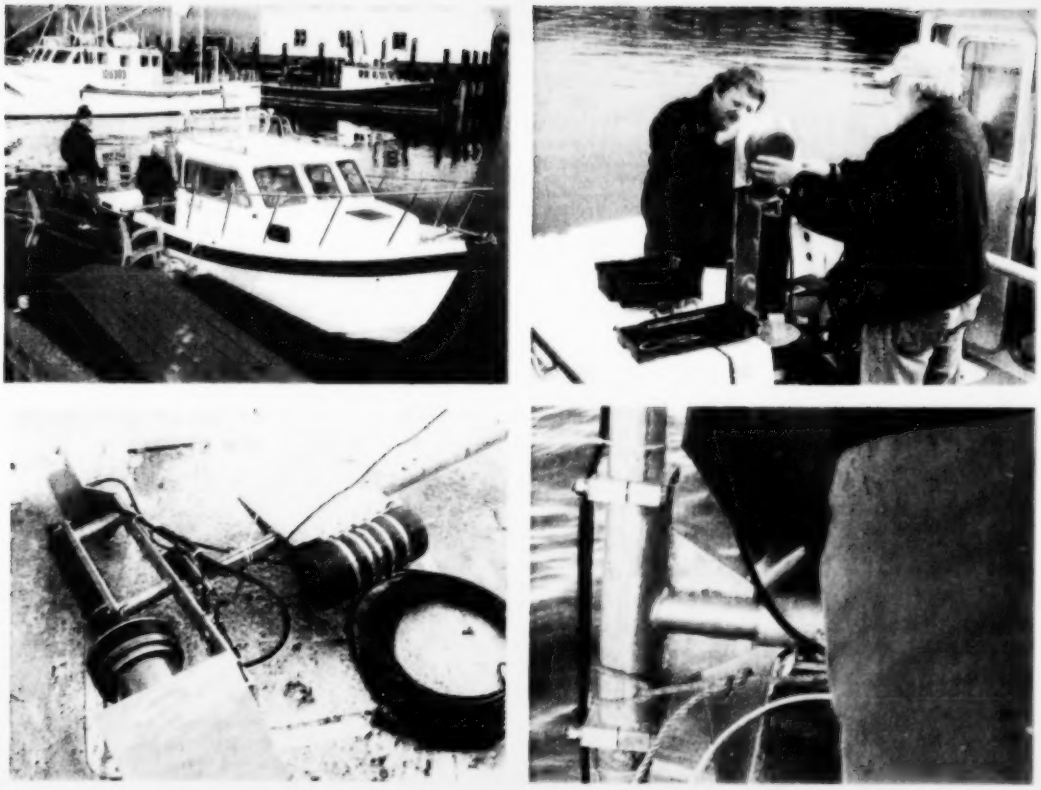

Figure 5. Photograph of the R/V *OSPREY* (upper left), EK60 120 kHz split beam transducer and MS2000 multi-beam sonar (upper right), pole mount configuration (lower left), and vessel side mounting bracket (lower right).

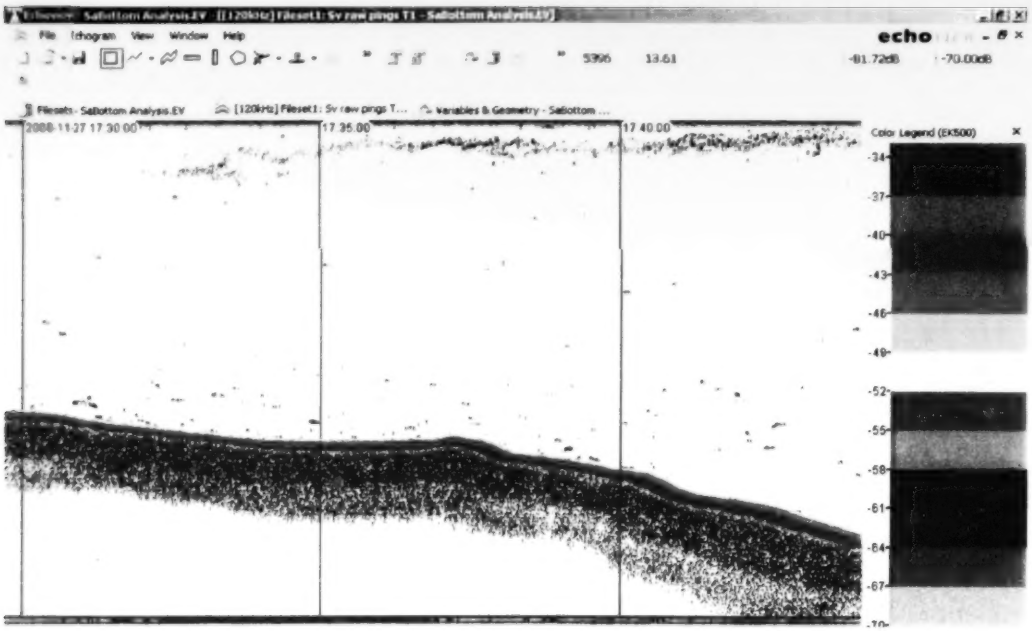

Figure 6. Standard echogram from a Simrad EK60 scientific echo-sounder viewed with Echoview acoustic editing software. The green line following the bottom is the sounder detected bottom. Volume backscatter (Sv) scale ranges from -34 to -70 dB.

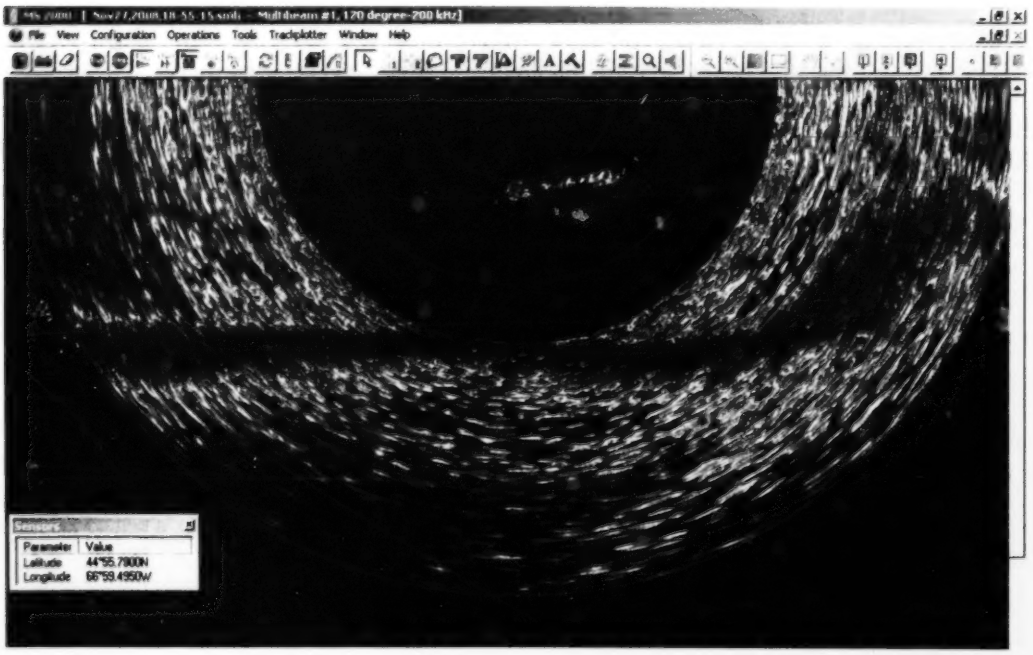

Figure 7. Standard single ping output from the Kongsberg Mesotech MS2000 multi-beam sonar. Note the small group of targets (fish) at about 20 m.

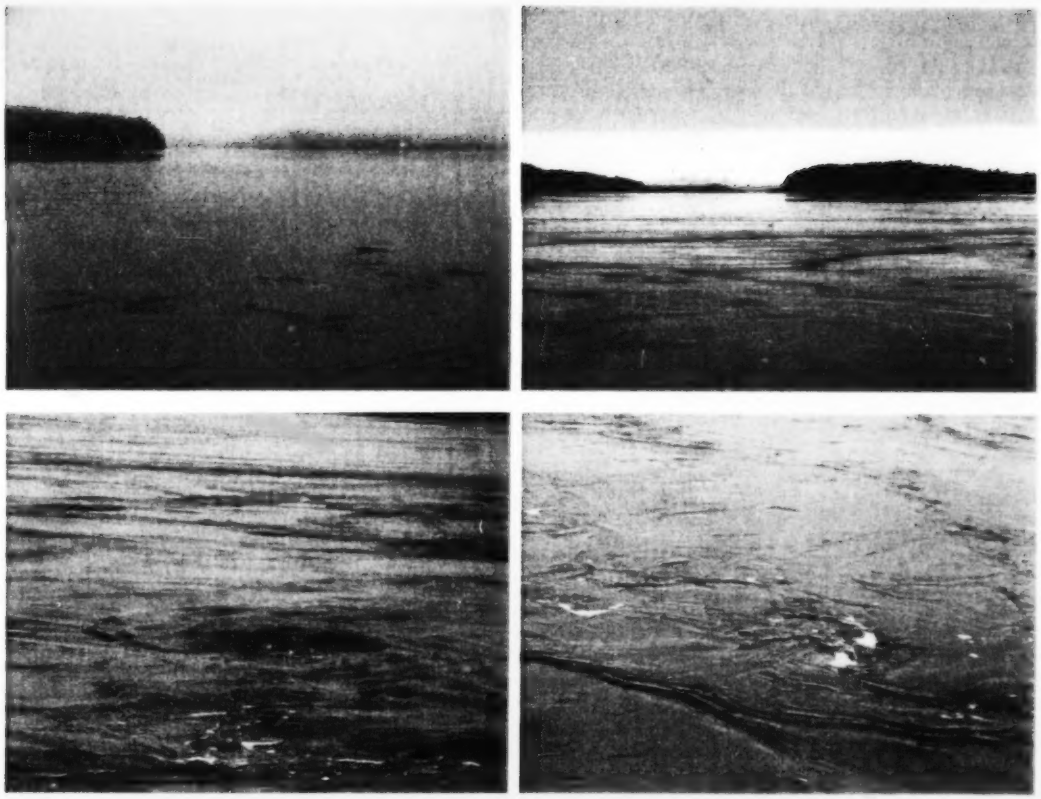

Figure 8. Photographs of calm water and turbulence near proposed tidal power development sites and the Old Sow in Western Passage on November 27, 2008.

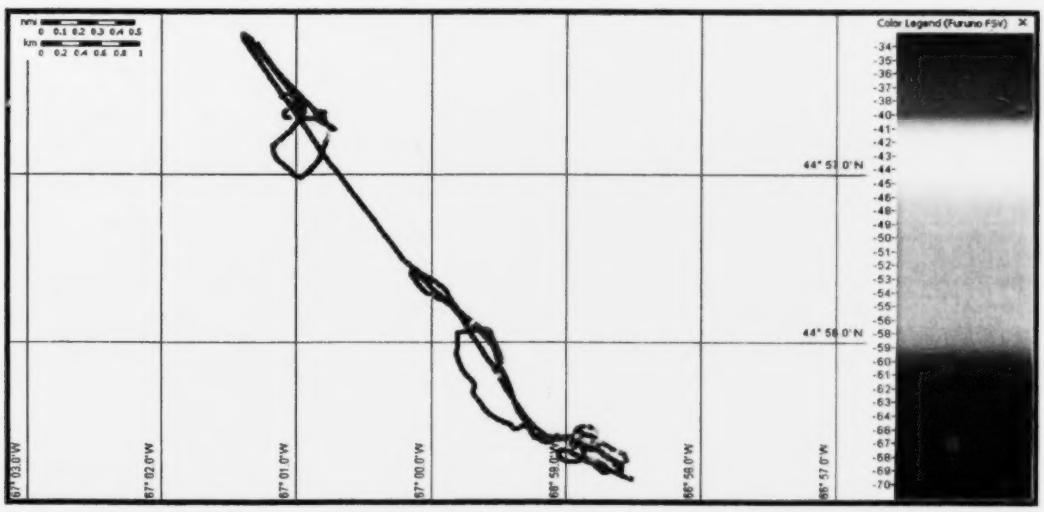

Figure 9. Distribution of acoustic backscatter along the Western Passage vessel track.

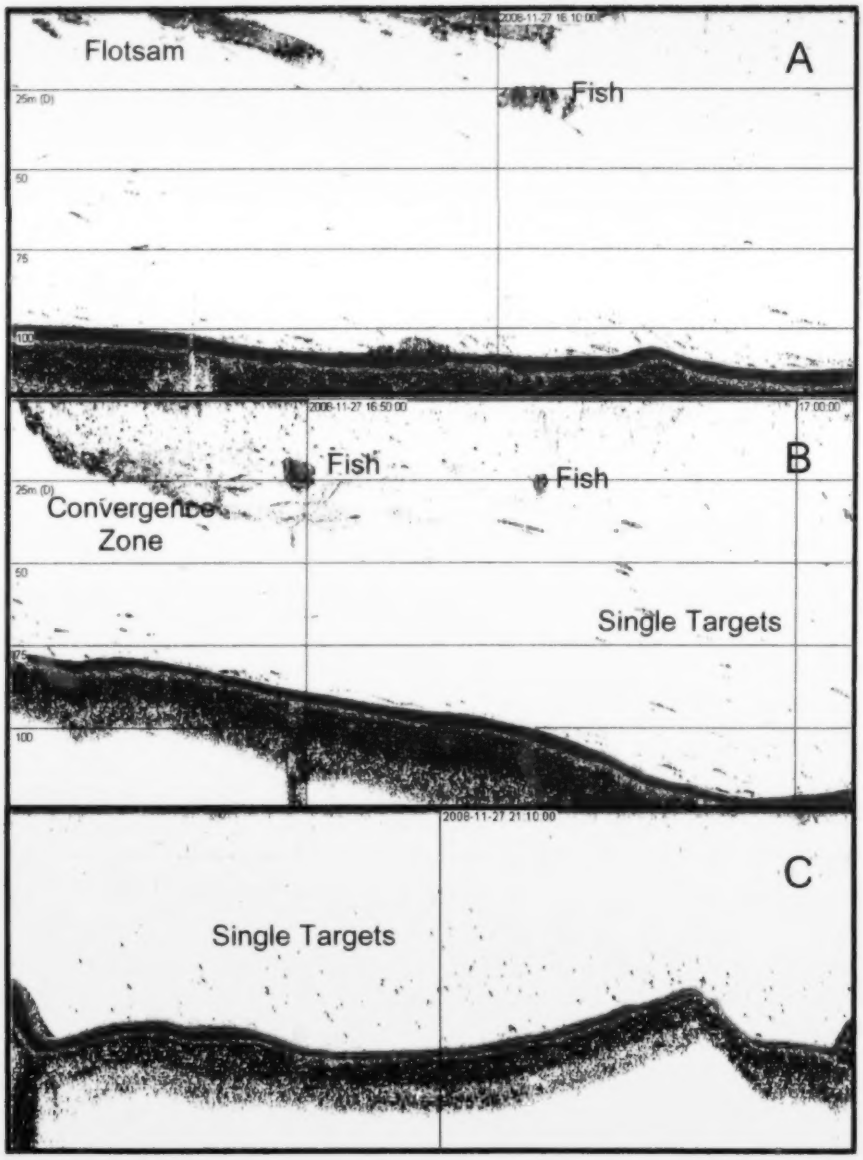

Figure 10. Echograms from proposed tidal development site 2 (A, B) and site 3 (C) illustrating the flotsam (rockweed), convergence zone, fish schools, and single targets.

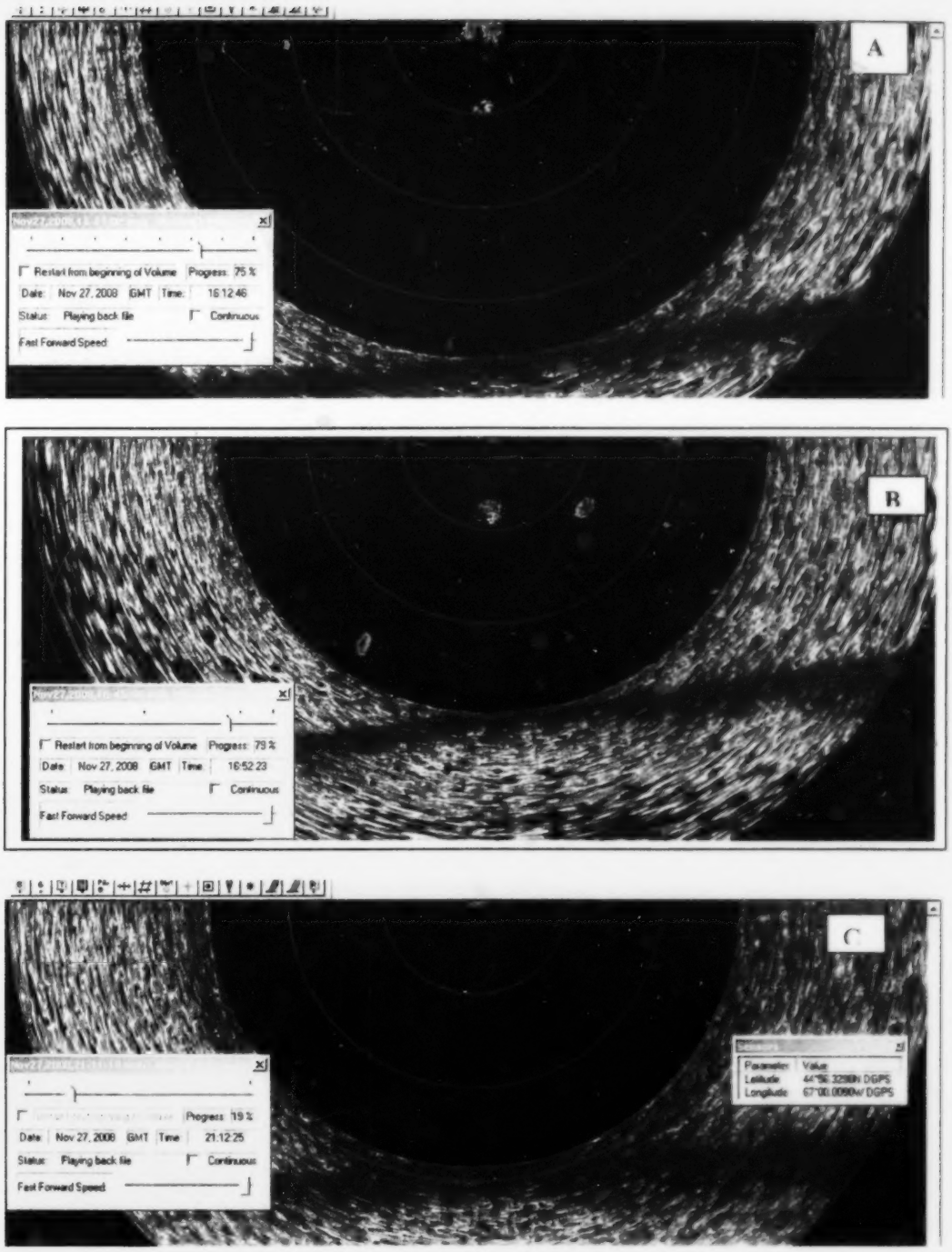

Figure 11. MS2000 multi-beam sonar images corresponding to a single ping from the echograms in Figure 10. Depth rings denote 30 m intervals for A and B and 20 m for C.

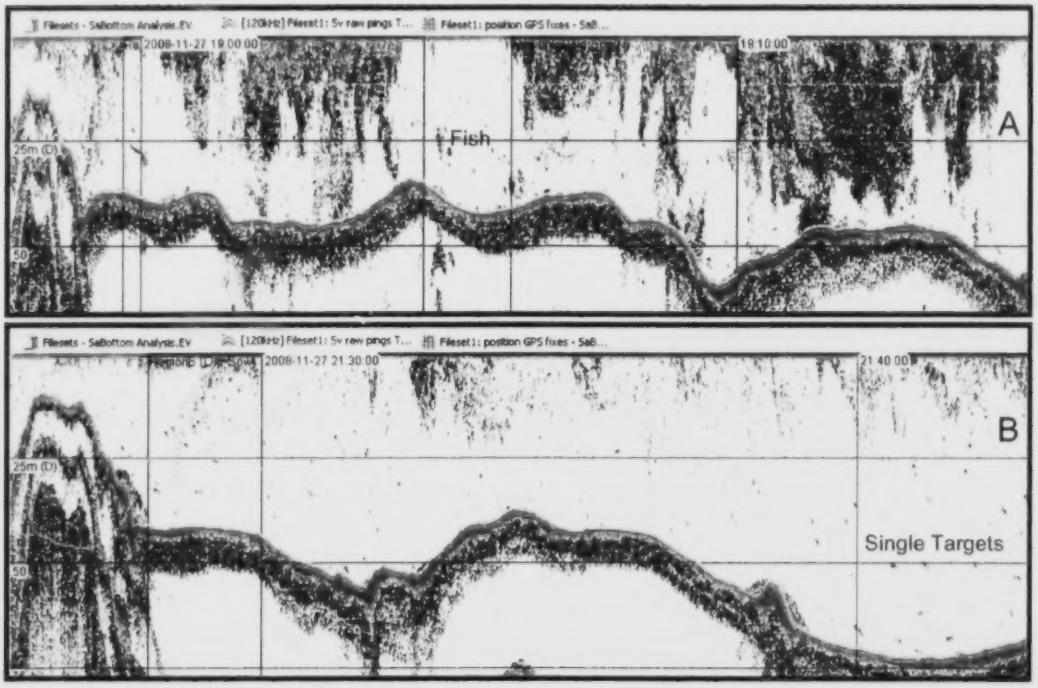

Figure 12. Echograms collected in approximately the same location near the Old Sow, Western Passage, NB during the high flow period (A) and slack tide (B). Note the strong backscatter in the upper water column associated with tidal turbulence (A).

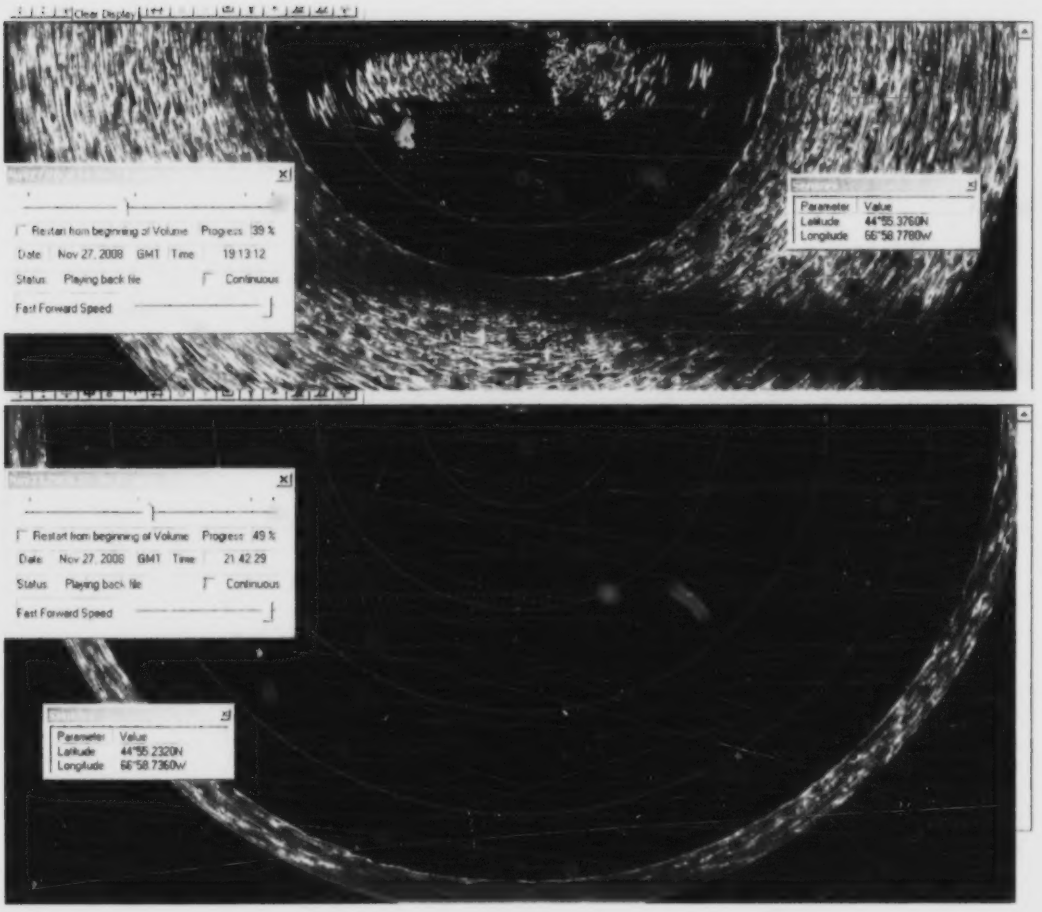

Figure 13. Corresponding Simrad MS2000 multi-beam sonar pings consistent with the echograms in Figure 12. Note: The time utilized to approximate the position in the echogram is calculated by assuming a two minute delay between the sounder and the sonar.

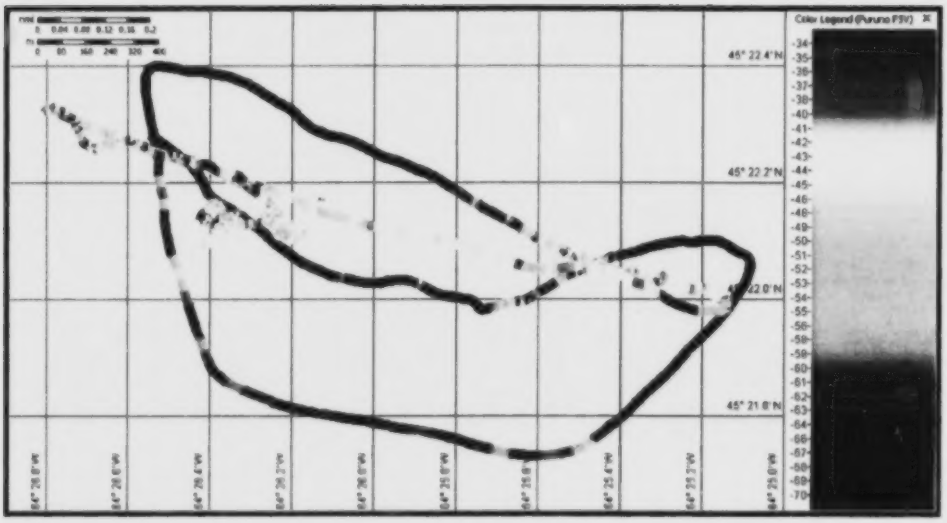

Figure 14. Distribution of acoustic backscatter (Sv) along the vessel track in Minas Passage near the Black Rock tidal development site.

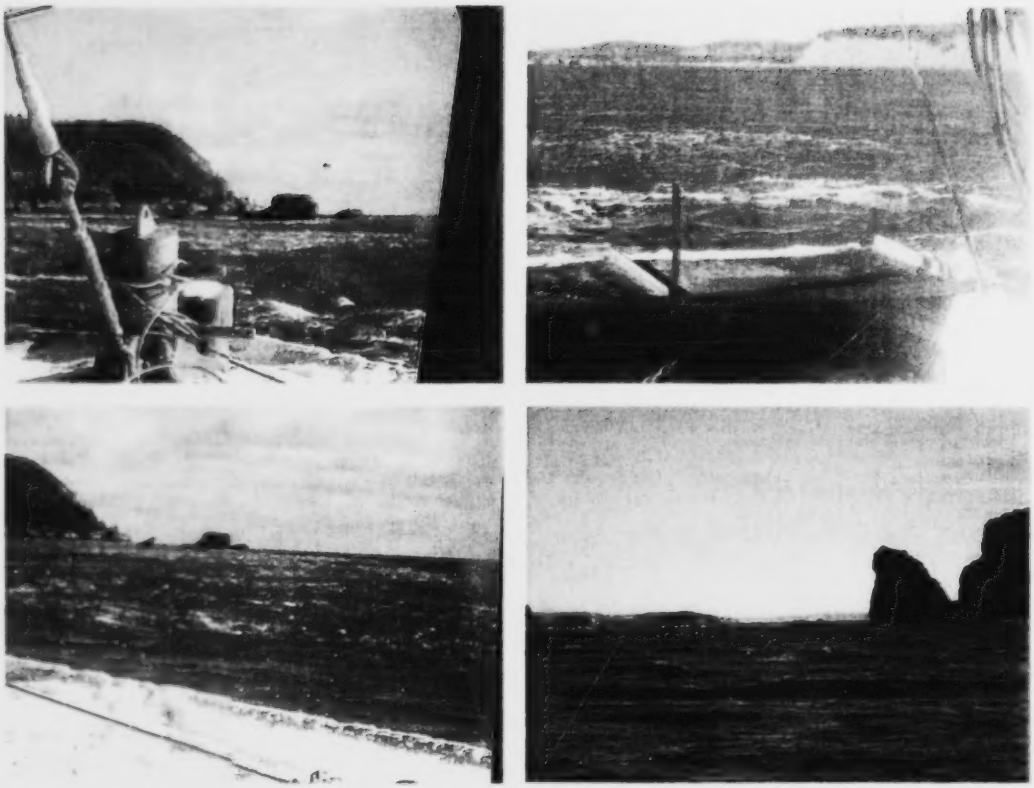

Figure 15. Photographs of water turbulence and wave action near Black Rock on January 10, 2009. Minas Passage viewed from near Cape Split (lower right).

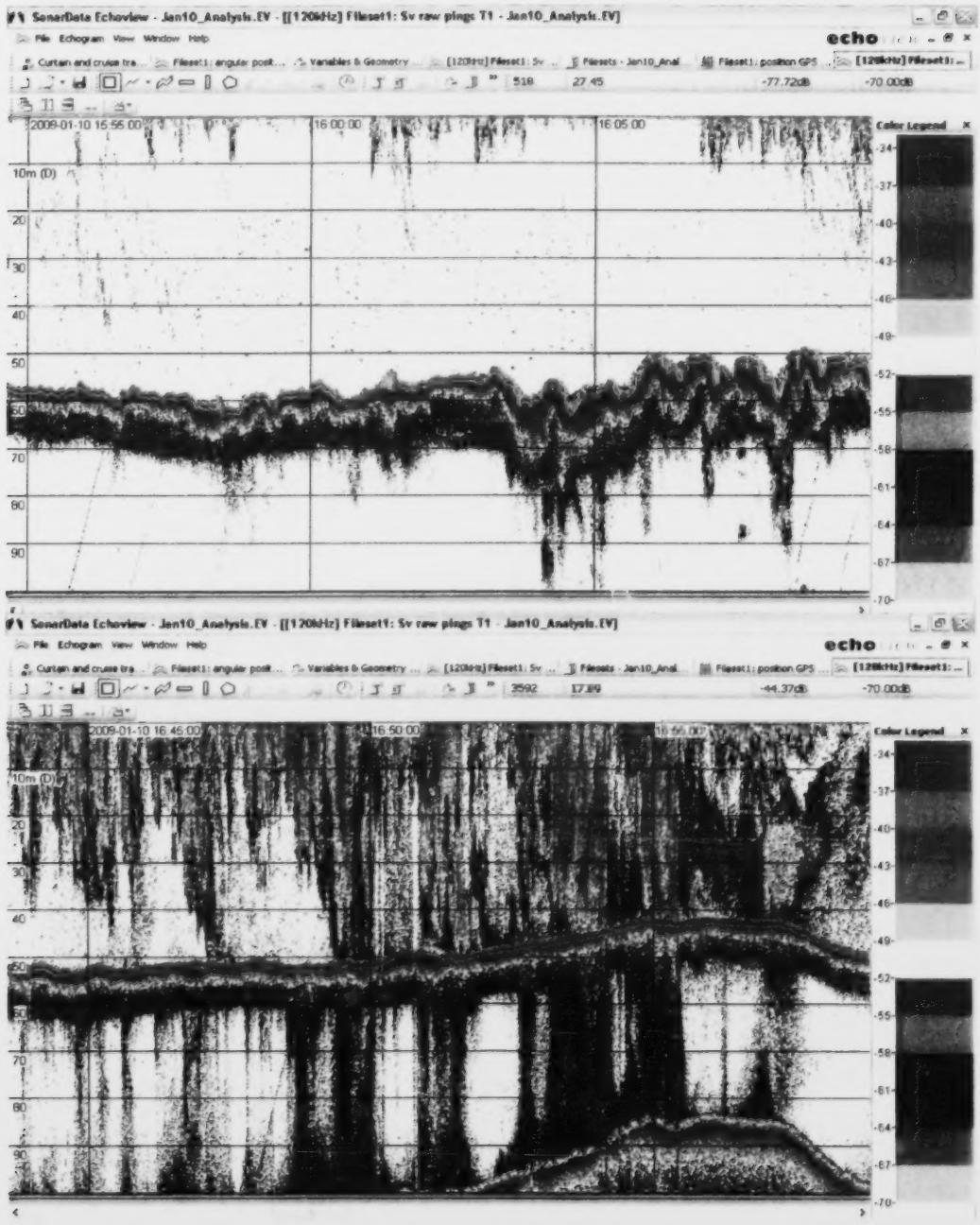

Figure 16. Echograms from a calibrated Simrad EK60 echo-sounder in Minas Passage near Black Rock: Upper panel – largely outside tidal rips, bottom panel – within tidal rips. Each echogram represents approximately 15 minutes of recording. Select multi-beam pings are shown in Figure 17. Note time differences.

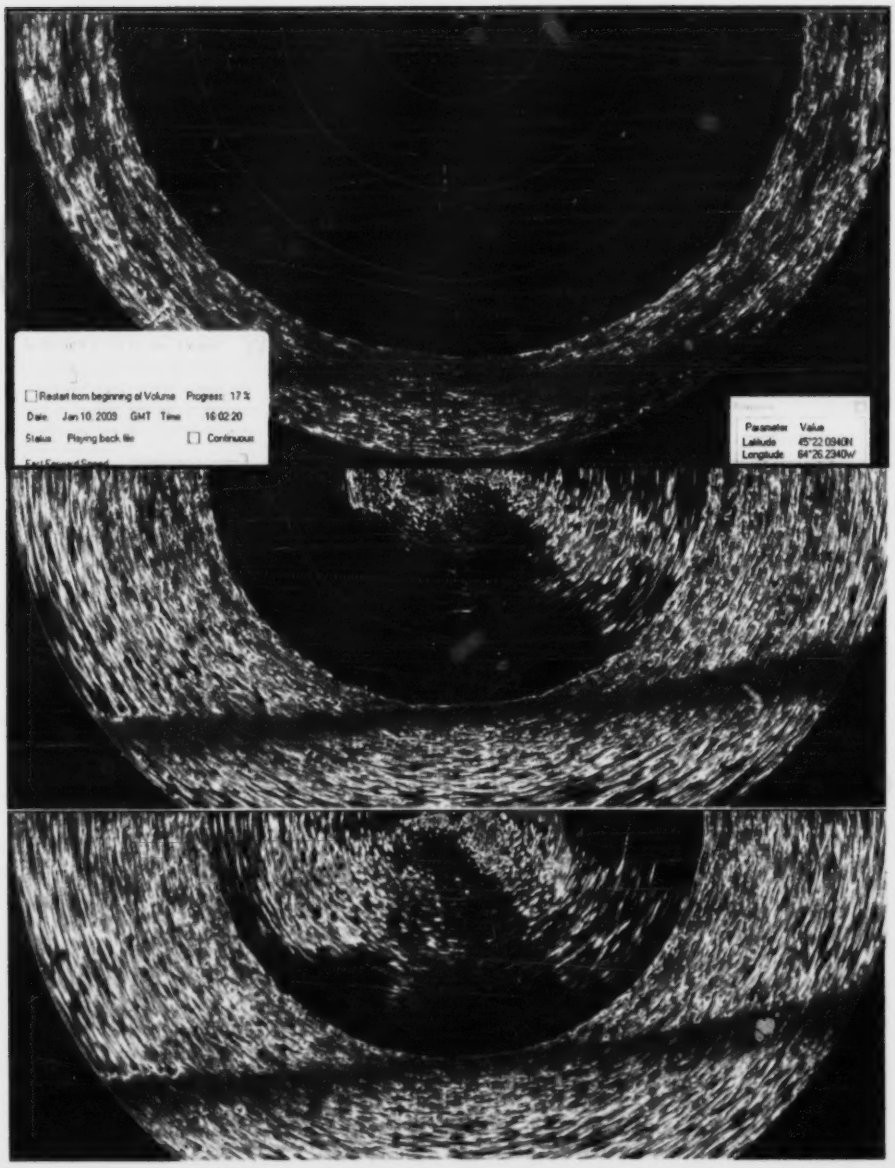

Figure 17. Single ping from the MS2000 at GMT 16:02.28 (A), 16:58:05 (B), and 16:58:12 (C) corresponding to the echograms in Figure 16. Note the 3:20 minute/sec difference between the sonar and echo-sounder time stamps.

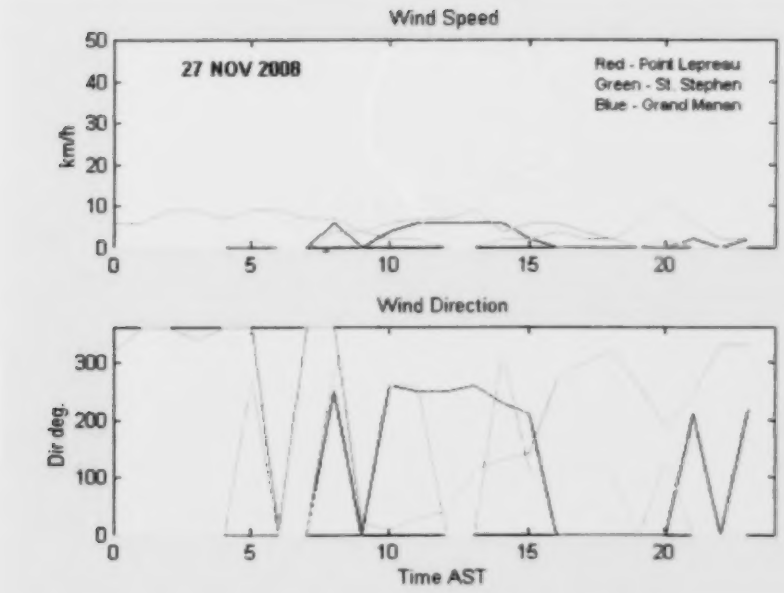

Figure 18. Wind direction and speed for three locations in the vicinity of Western Passage on November 27, 2008. Source: Environment Canada, National Climate Data and Information Archive

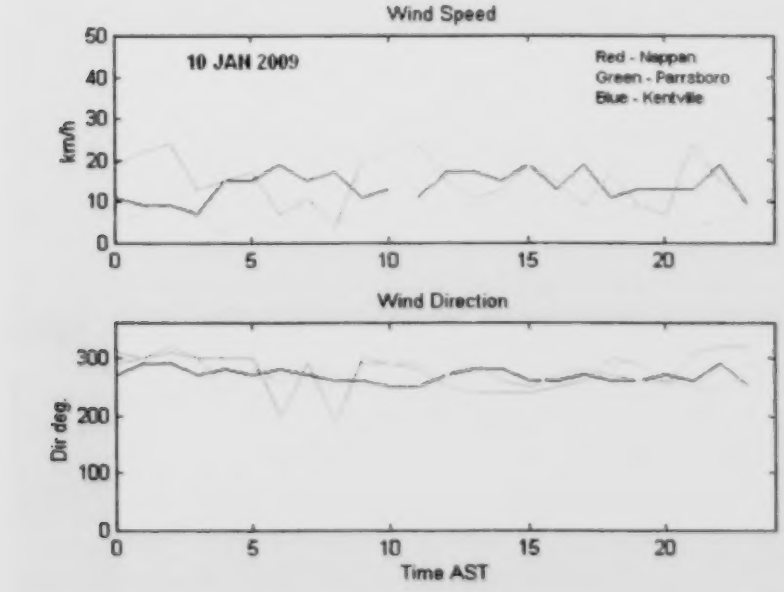

Figure 19. Wind direction and speed for three locations in the vicinity of Minas Passage on January 10, 2009. Source: Environment Canada, National Climate Data and Information Archive

APPENDIX: REGRESSION ANALYSIS OF ACOUSTIC BACKSCATTER S_a

A major concern with quantitative acoustic techniques in highly aerated waters is the potential for anomalous acoustic attenuation. To investigate we compared upper water column and bottom depth-integrated backscatter (S_a). Ten (10) ping averages of S_a for both the surface 25 m and a 1 meter bottom window starting 0.5 m below echo-sounder detected bottom were examined. Overall 1643 ten-ping averages were collected during the study in Minas Passage (Table A1) and in the Old Sow area of Western Passage (Table A2). The frequency distributions for the surface and bottom S_a values in both study areas are shown in Figures A1 and A2. At both sites a wide range of integrated backscatter values were observed in the top 25 meters of the water column, and a more restricted range for the bottom window. It should be noted that at the 120 kHz acoustic wavelength of 1.2 cm the bottom echo is generated by an "incoherent" rough surface scattering process which, in integration, should be approximately compensated for variable bottom depth (range) by the 20 log R time variable gain used in the echo-sounder.

To investigate if there was any relationship between the backscatter in the water column and the bottom echo, possibly indicating bottom echo attenuation due to anomalous acoustic attenuation in the water column strongly backscattering regions, the S_a in the top 25 meters was regressed against the S_a for 1 meter of bottom (Figures A3 and A4). The data were also sub-sampled to select only surface S_a >-40, >-35 and > -30 dB to insure that no relationship was obscured by non-linearities or sounder signal thresholds. In all cases no significant relationship was found, thus implying that there was no observed anomalous signal loss in the water column backscattering regions.

Table A1. Descriptive statistics for surface (25 m) and bottom backscatter (dB m^2/m^2) collected in Minas Passage on January 10, 2009.

	Number	Mean	Min	Max
Surface	971	-36.31	-72.36	-25.43
Bottom	971	-10.55	-36.55	-6.11

Table A2. Descriptive statistics for surface (25 m) and bottom backscatter (dB m^2/m^2) collected in the Old Sow on November 27, 2008.

	Number	Mean	Min	Max
Surface	672	-31.24	-70.97	-8.87
Bottom	672	-11.53	-40.37	-3.87

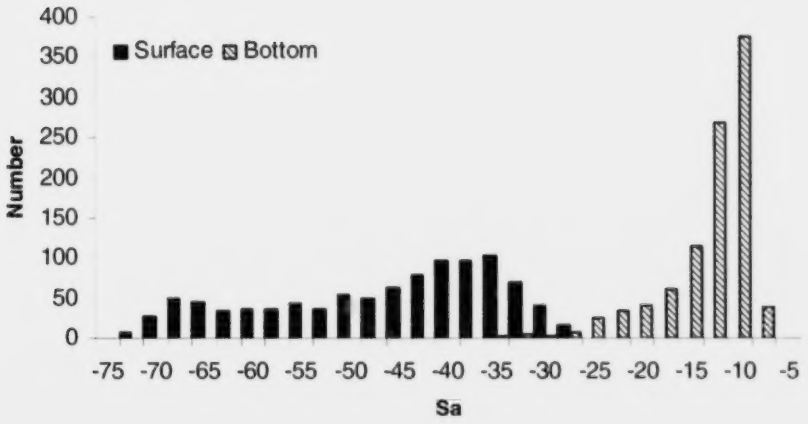

Figure A1. Frequency distribution of depth-integrated acoustic backscatter per 10 ping interval for the upper 25 m of water column and 1 meter of bottom from Minas Passage.

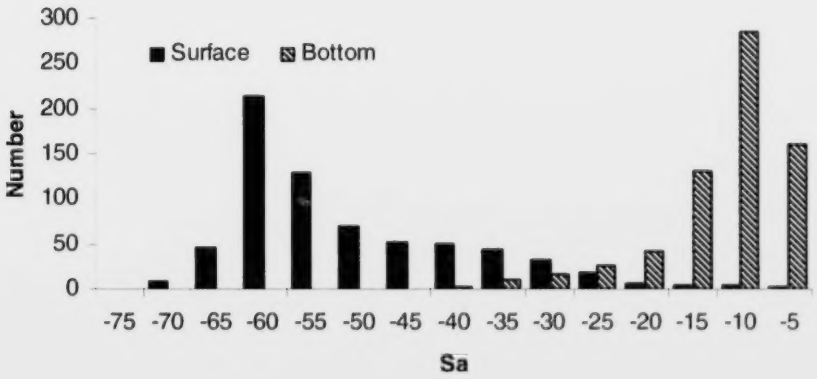

Figure A2. Frequency distribution of depth-integrated acoustic backscatter per 10 ping interval for the upper 25 m of water column and 1 meter of bottom from the Old Sow in Western Passage.

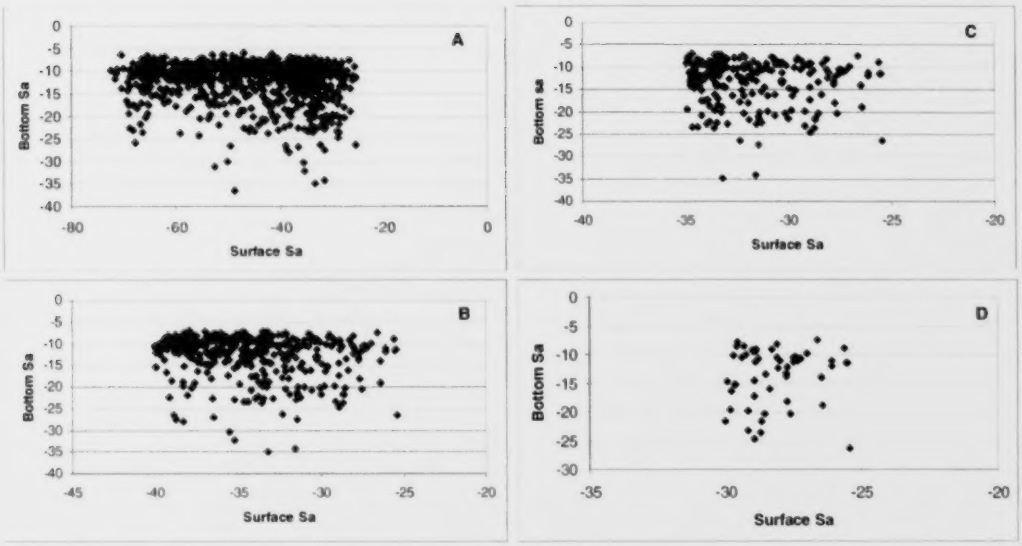

Figure A3. Scatter plot of integrated bottom backscatter (dB m^2/m^2) versus upper 25 m water depth-integrated backscatter from Minas Passage for all samples (A) and water column backscatter <40 dB (B), <35 dB (C) and <30 (D).

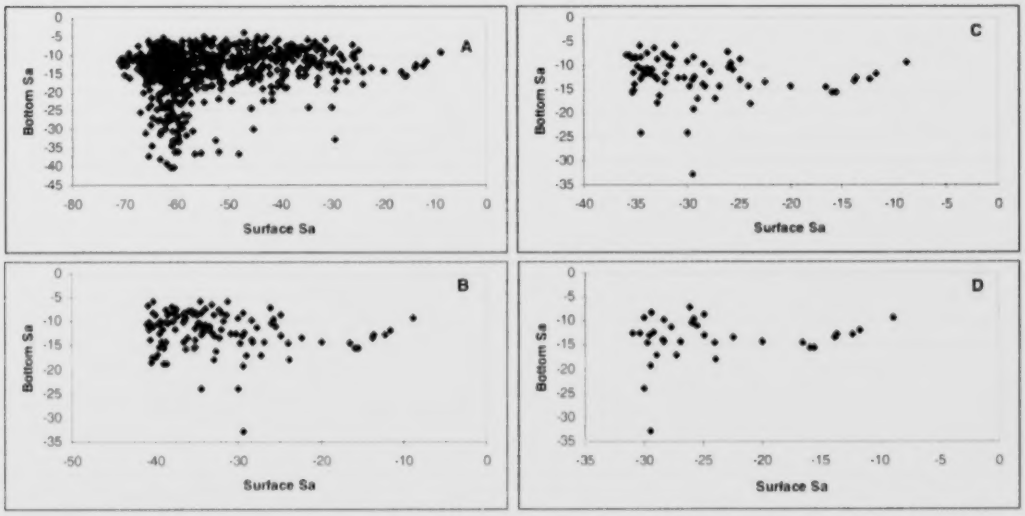

Figure A4. Scatter plot of integrated bottom backscatter (dB m^2/m^2) versus upper 25 m water depth-integrated backscatter from the Old Sow for all samples (A) and water column backscatter <40 dB (B), <35 dB (C) and <30 (D).